EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
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CERN - PS DIVISION

PS/ OP/ Note 98-20

# SYNTHESIZED/MEASURED BTRAIN & SOFTWARE

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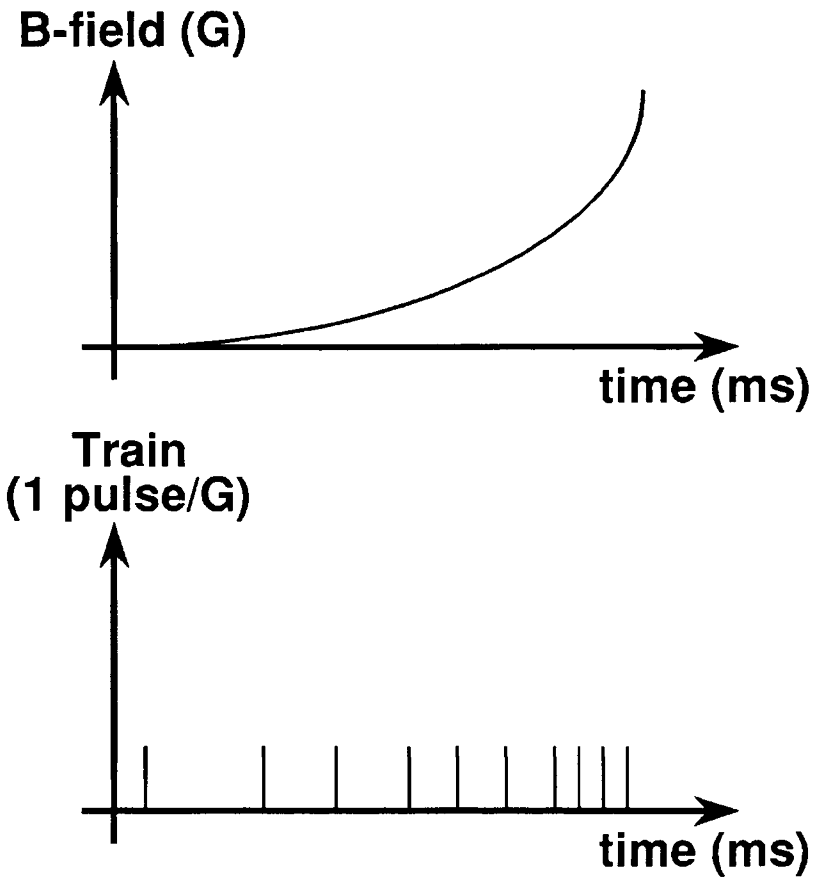
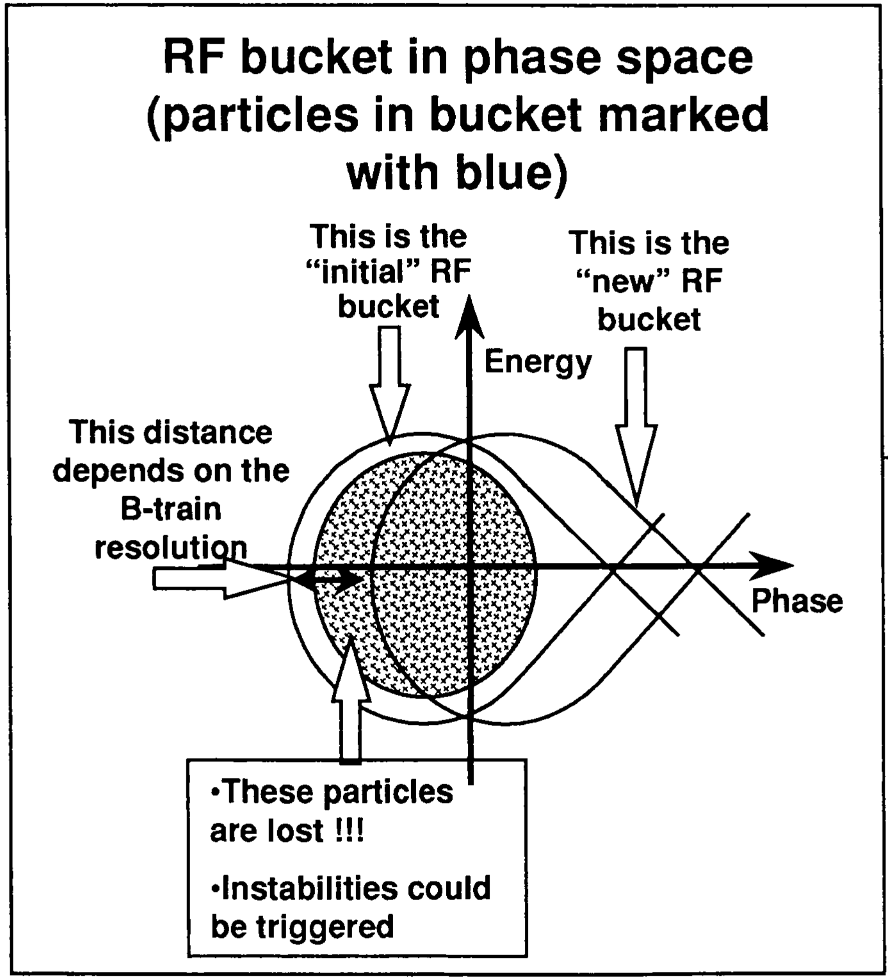
Geneva, Switzerland
16 March 1998

# B-train, what and why?




- Pulse train marking a predefined fractional increase of magnetic field in an accelerator
- Used for:
  - Programming of magnets which correct inhomgenities and sets the Tune (Q-value)
  - Digital longitudinal beam control
  - Field (energy) dependent measurements

# Specification for PS Booster B-train




- Digital Beam Control: RF frequency programmed as function of measured integral B-field
  - 1 G precision
    - radial position
  - 0.1 resolution
- Programming of correction magnets
  - 10 G precision
  - 1 G resolution
- Measurements
  - 10 G precision
  - 1 G resolution

# Methods for B-field measurements

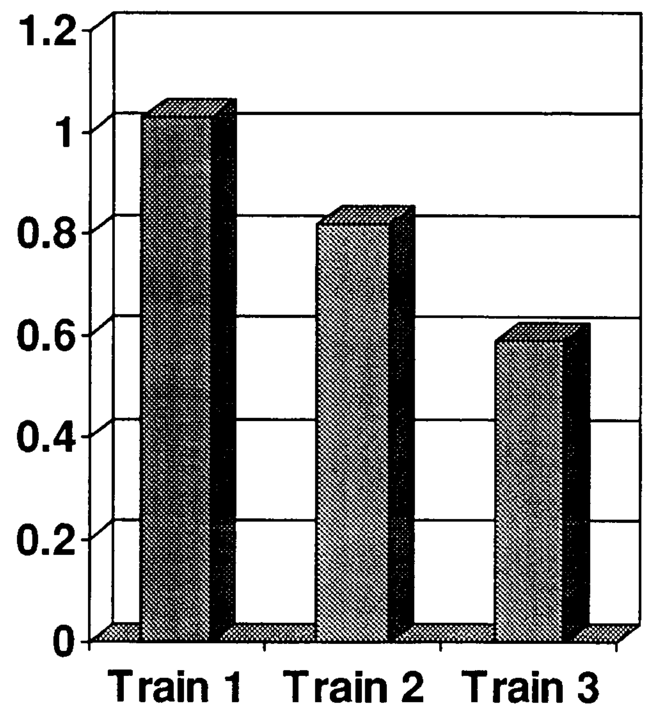
- **Dynamic measurements in reference magnet**
  - Integral field measurements
    - Long coil measurements including edge effects (eddy currents)
    - Long coil measurements well inside magnet yoke
- **Static measurements**
  - Classical methods used for mapping and testing of magnets in laboratory environment
  - Local field measurements
    - NMR, Hall or Peaking strip measurements
- **Beam measurements**
  - Radial position as a function of RF-frequency gives the integral B field (Bdl)
  - Beam Transfer Function measurements of field ripple

# B-trains at the PS Booster

- **Measured B-train**
  - Long coil measurement in reference magnet (coil within magnet yoke)
  - NMR marker used to start train
  - 0.02% precision, 1 G resolution, up only
- **Synthesised B-train**
  - Calculated using the control values for the power supply and a theoretical magnet model
  - 0.01% precision, arbitrary resolution, up and down.

# Comparison (measured gitter) of PSB B-trains

- Measurement done at 6849 G
- The time difference between the B-train pulse and an NMR-marker at 6849 G measured
  - Standard deviation in Gauss derived from known dB/dt.
- Train legend:
  - Train 1: Measured B-train without NMR start
  - Train 2: Measured B-train with NMR start
  - Train 3: Synthesised B-train



# Why do we need magnetic markers for B-train generation?

- The integration coil does not give information on the remnant magnetisation
- Magnetic markers(flat top mode) have been provided (e.g. CERN-SPS) to reduce gain drift and offset drift problems in V/F type integrators in order to improve on long term stability of the B-train
- Magnetic markers are very useful for machines with a flat bottom cycle.
- Magnetic markers can increase the B-train accuracy when the magnets approach saturation.

# Review of magnetic markers (1)

- **Peaking strip:**
  - The "peaking strip" is a zero detector. It is a mechanically pre-stressed needle of ferromagnetic material (typically in a glass tube)which changes abruptly its state of polarisation when the field seen by the needle passes through zero.
  - The peaking strip needs an external compensation coil if required to operate at fields different from zero. This limits the practical range of use to about 500 Gauss due to the thermal load of that DC operated coil.

# Review of magnetic markers (2)

- **NMR marker:**
  - NMR(nuclear magnetic resonance) markers have been used on the flat-bottom and flattop since the late 80s in the normal mode of operation in the CERN-SPS. This requires a measurement time of at least 0.3 seconds and a stable value of the field over that period.
  - Certain NMR instruments can easily be modified to be operated in a ramp mode (i.e. on the slope of the ramped B-field) by turning off the internal auxiliary B-field modulation on the probe and using an external synthesiser as RF source.
  - In the ramp mode NMR probes haven given a useful signal (bip) for slew rates higher than 2 T/s. But note that all NMR probes require a rather homogeneous B-field. Inhomogeneous fields can be corrected to some extend by using gradient correction coils and/or shims.

# Review of magnetic markers (3)

- **NMR probes: (continues)**
  - The range of operation for typical NMR probes starts around 400 Gauss and extents beyond 100 kG. Thus they are complementary to the peaking strip. For very small fields ESR (electron spin resonance) probes can be used . But also ESR probes require a rather homogeneous field.

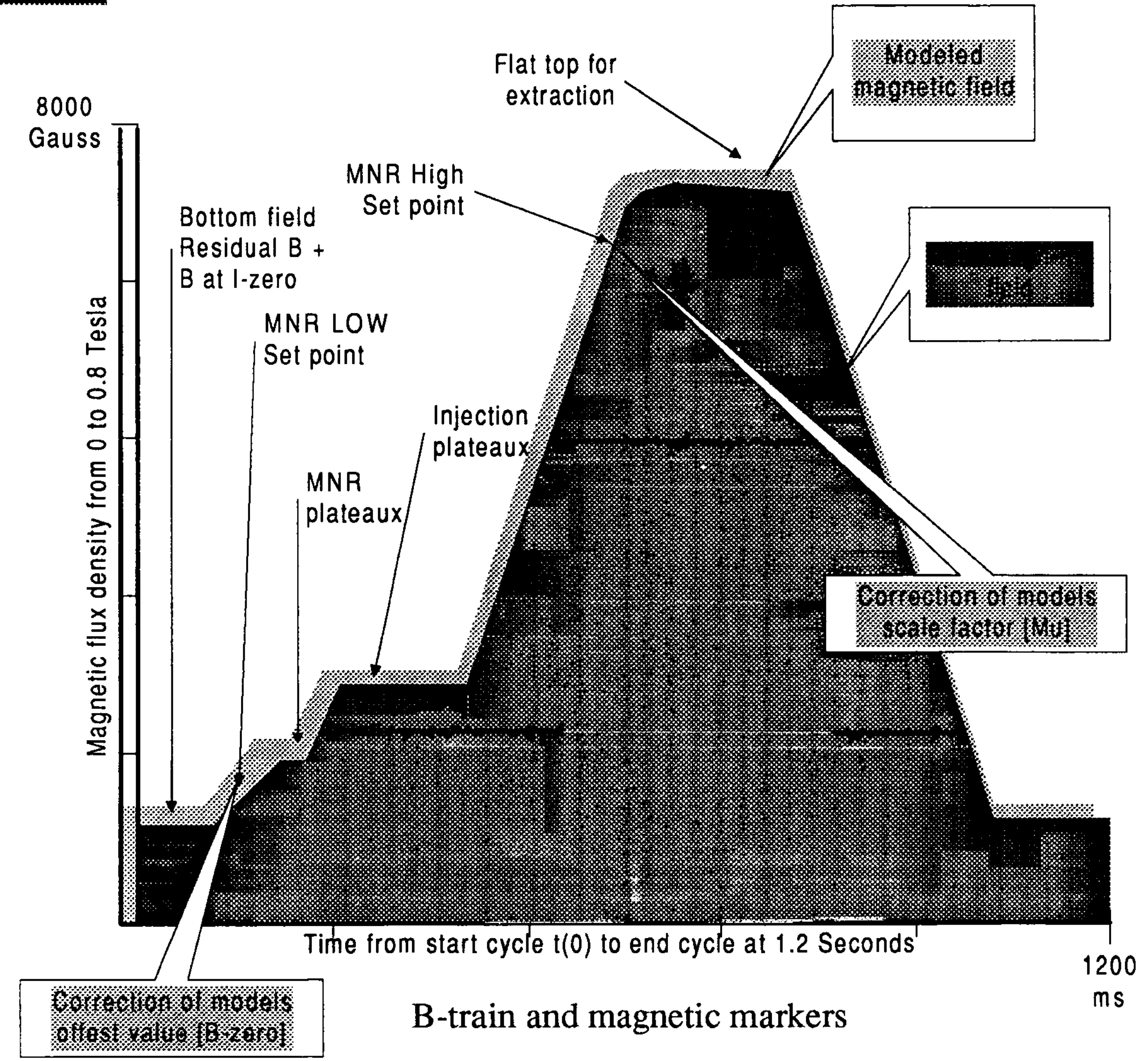
# Review of magnetic markers (4)

- **FMR (Ferrimagnetic resonance):**
  - FMR (ferromagnetic resonance) is a special kind of ESR but can work with a tiny probe size(very insensitive to gradients). The probe is a ferrite sphere with less than 0.5 mm diameter, to be magnetised into its saturation (typically>500 Gauss). It is a magnetically tuneable microwave transmission resonator ($F_{res}$= 2.8 GHz/kG) with the possibility of static readout (no field modulation required). Similar structures are known as YIG filters. A disadvantage is the rather low Q for polycrystalline ferrite (around 1000) and the high frequency range.

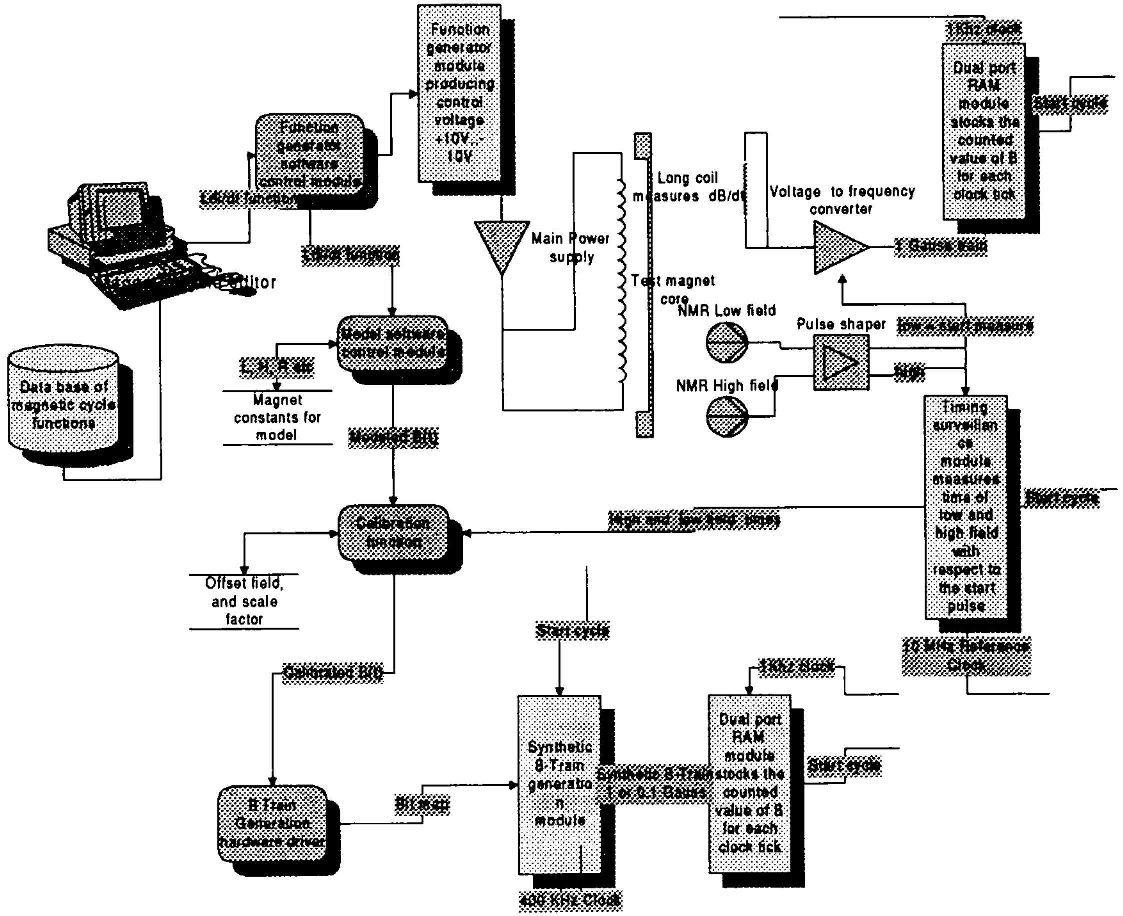
# Review of magnetic markers (5)

- **Hall probe:**
  - Hall probes work well in static fields with a precision of $10^{-4}$ . But there are question marks about the validity of the readout in fast ramps. In comparison to NMR, ESR and FMR the reading of many Hall probes is rather sensitive on its orientation to the field. Hall probes may be more susceptible to ionising radiation than NMR ,ESR and in particular FMR which can stand very high radiation levels.

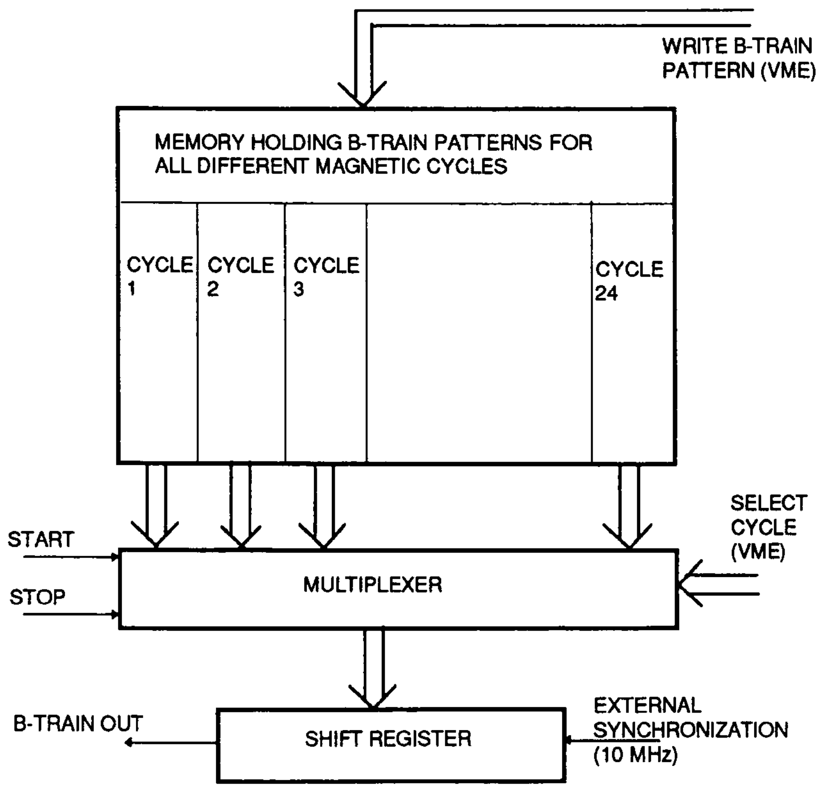
# Calibration of synthesised B-train



# Logical Layout of synthesised B-train

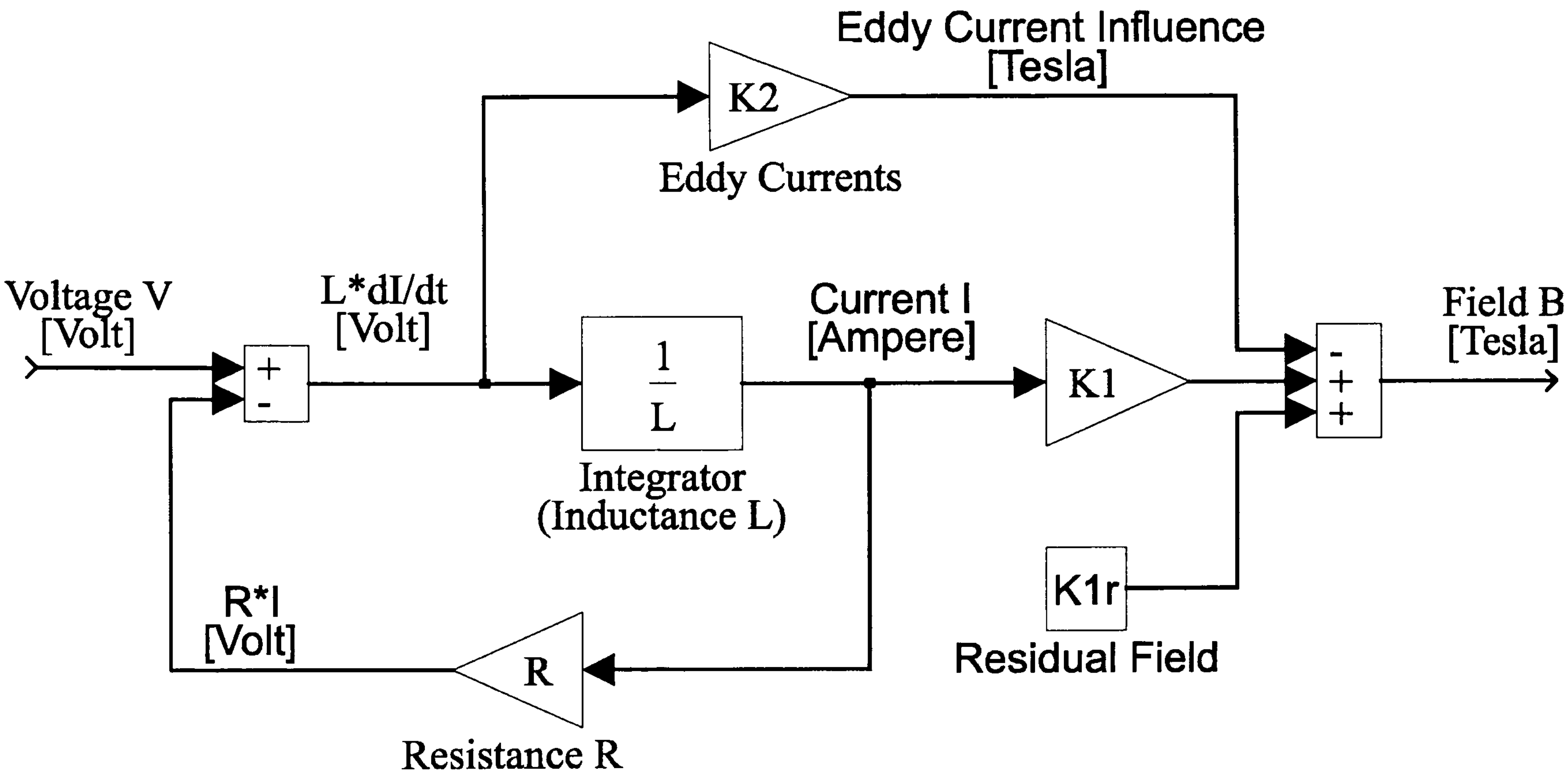


# Hardware layout synthetic B-train




- B-TRAIN GENERATOR is a VME module generating the actual pulses
- For every possible magnetic cycle, the calculated B-train pattern is loaded off-line into the memory
- At the beginning of a cycle, a RT program selects the B-train pattern corresponding to the actual user
- During the cycle, a shift register shifts the pattern serially out thus forming the B-train

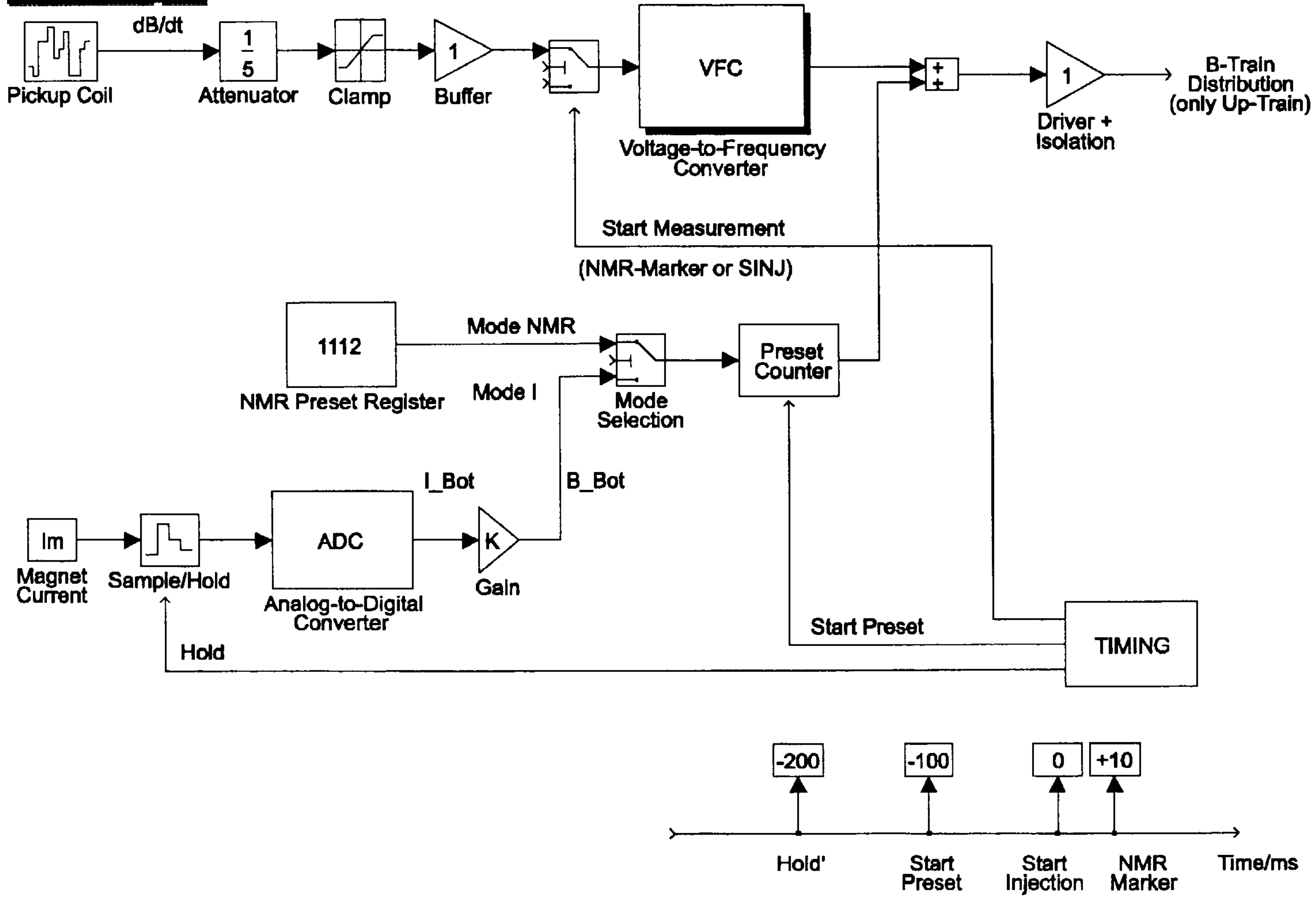
# Theoretical magnet model (1)



# Theoretical magnet model (2)

- Parameters independently accessible
  - **Inductance L: Saturation Effects**
  - **Resistance R: Temperature Influence**
- All Electrical Signals available
  - **Voltage V**
  - **Current I**
  - **Field B**
  - **L*dI/dt**
- Implementation of Second Order Effects
  - **Eddy Currents in the Laminations**
  - **Residual Field**

# Existing measured B-train at the PS Booster




Block-Diagram of Booster B-Train Generator

B-train and magnetic markers

27/2/98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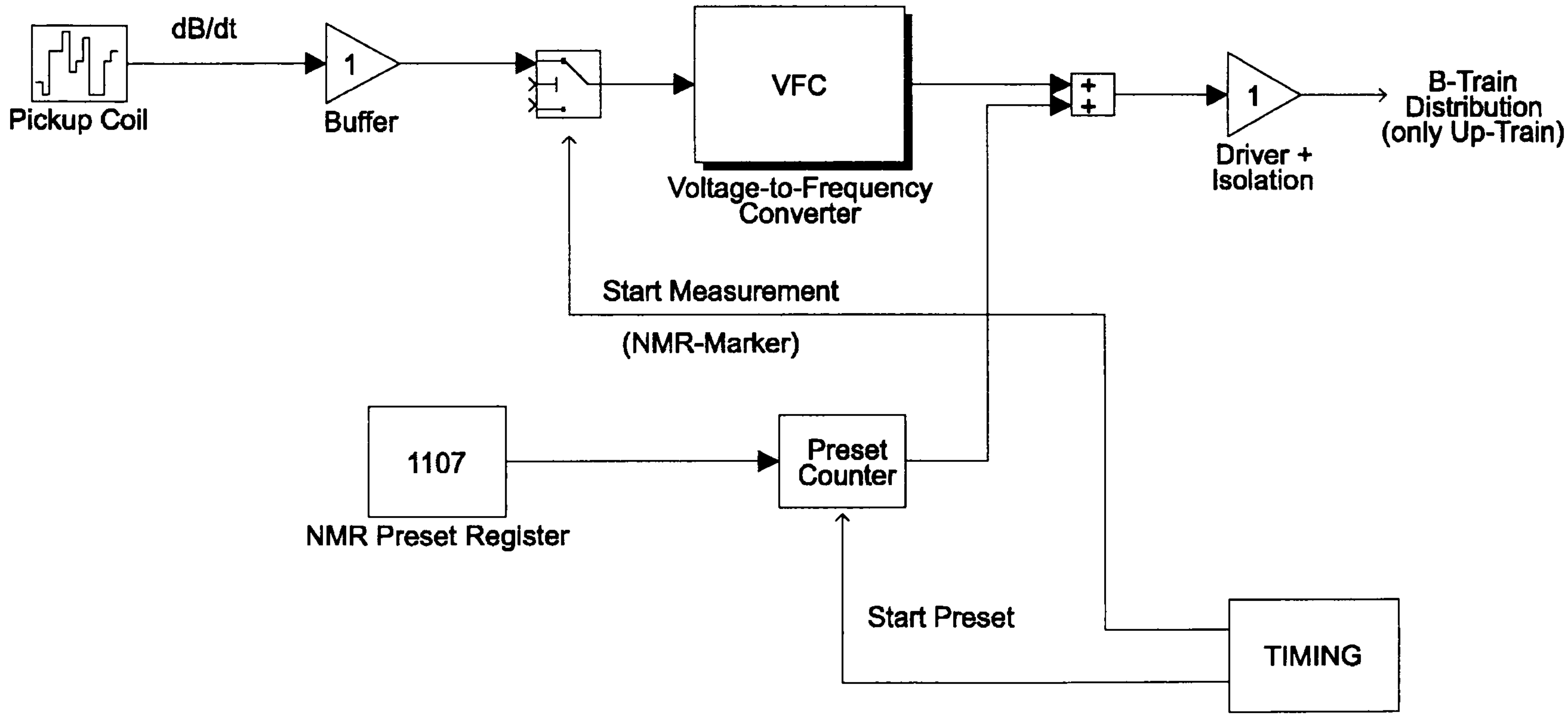
CERN, PS/PO


Nice 95

# Simplified existing measured PS Booster B-train (1)




Simplified Block-Diagram of Booster B-Train Generator

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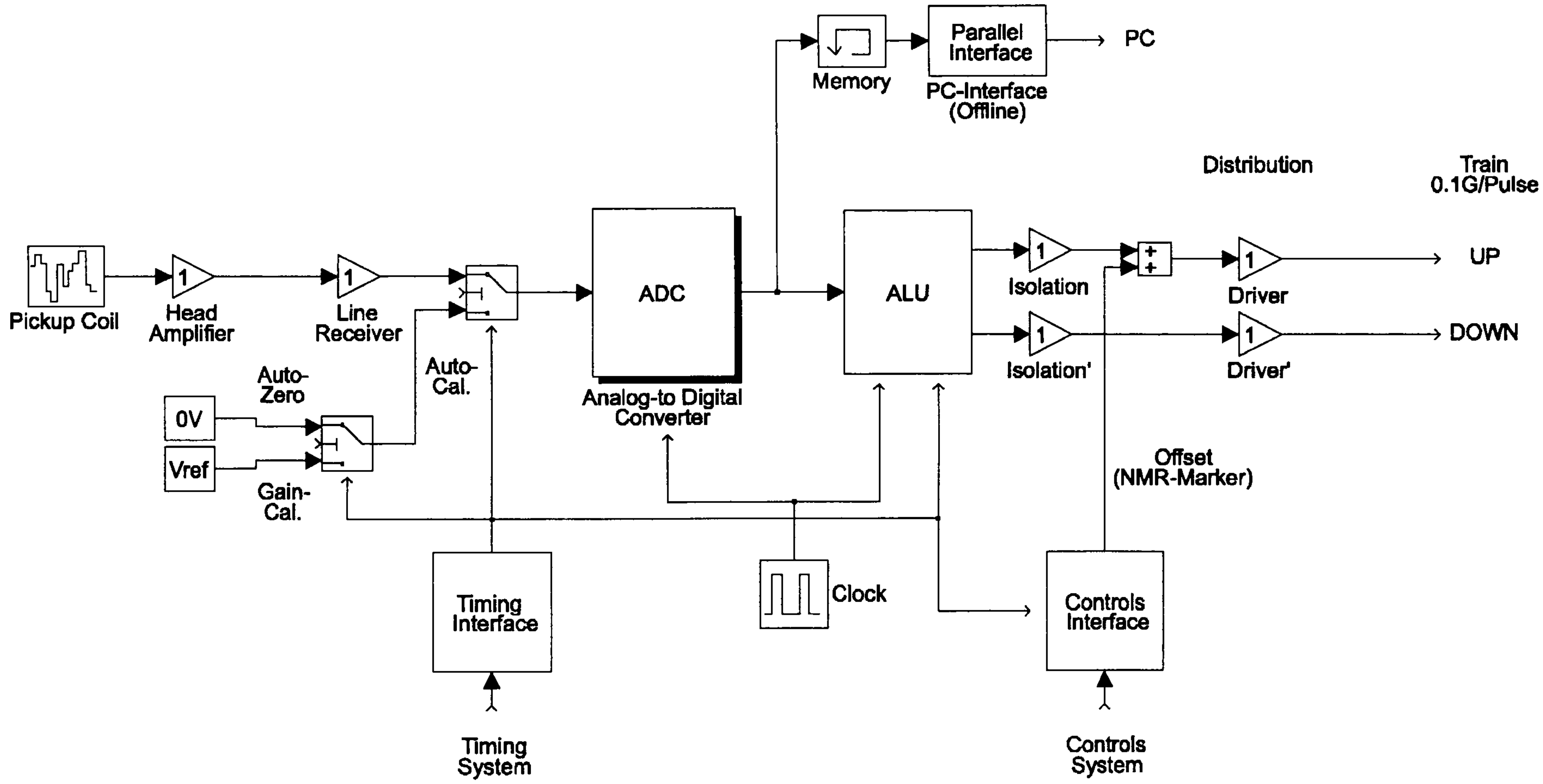
# Simplified existing measured PS Booster B-train (2)

- Principle:
  - **Voltage-to-Frequency Converter, Temperature stabilised**
- Up-Train only
- Resolution: ±1 Gauss (~100 ppm 0f FS)
- Reproducibility: 100 ppm
- Stability: 0.1%

# Proposed new PS Booster
# B-train




Block-Diagram of a B-Train Generator using an ADC

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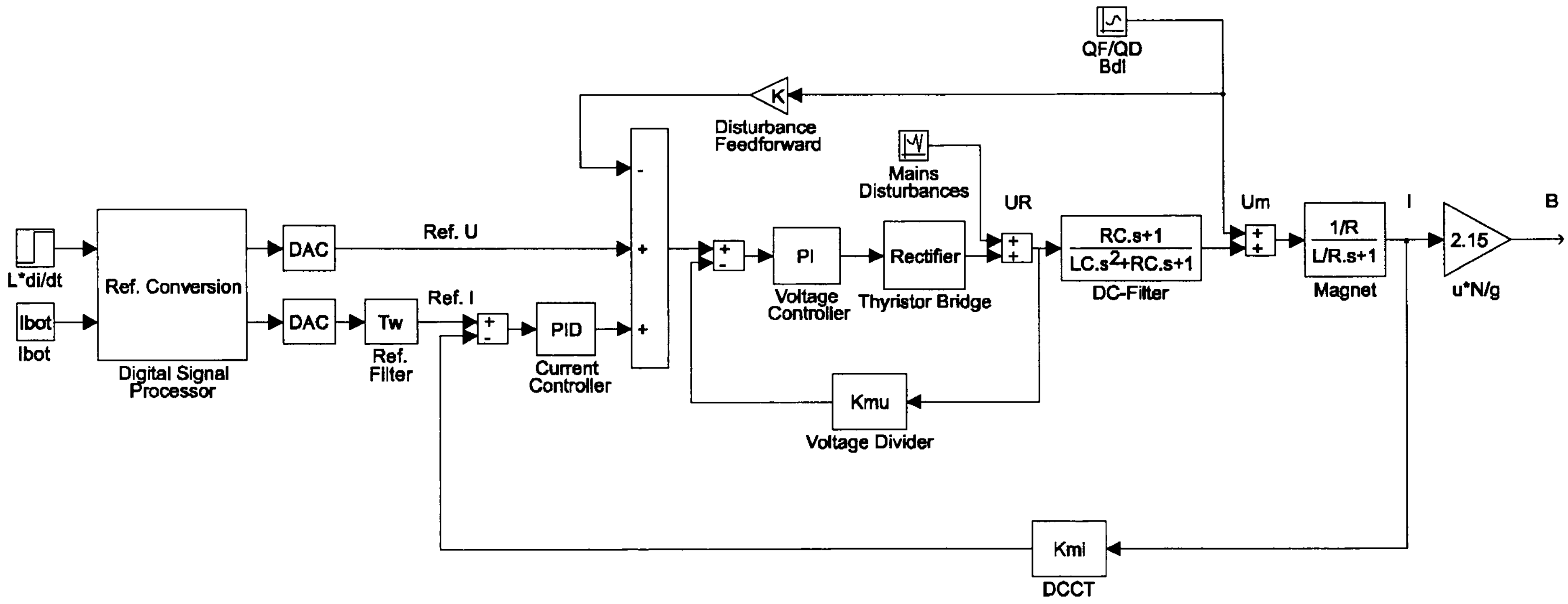
# Specifications for future PS Booster B-train

- Resolution: 0.1 Gauss (7…12 ppm)
  Up- and Down-Train
- Stability/Reproducibility: 10 - 20 ppm
- Bandwidth: B > dB/dt Max / Res. (for real time meas. with error < Res.)
- Nonlinearity: ~20 ppm

# Expected performance of future PS Booster B-train

- Principle:
  - **Analogue-to-Digital Converter with succeeding digital Full-Adder (e.g. NCO) to derive the Up-/Down-Train.**
- Resolution: 0.1 Gauss
- Dynamic Range (dB/dt): 15 Bit + sign
- Stability/Reproducibility: ~20 ppm (1 LSB of 16 Bit)
- Nonlinearity: ~20 ppm (1 LSB of 16 Bit)
- Bandwidth: B > 40KG/sec / 0.1G = 400KHz
- Digital Offset Correction (Auto-Zero)
- Digital Gain Correction (Auto-Calibration)

# PS Booster magnet control feed-back loops(1)




Block Diagram of the Booster Feedback Loops

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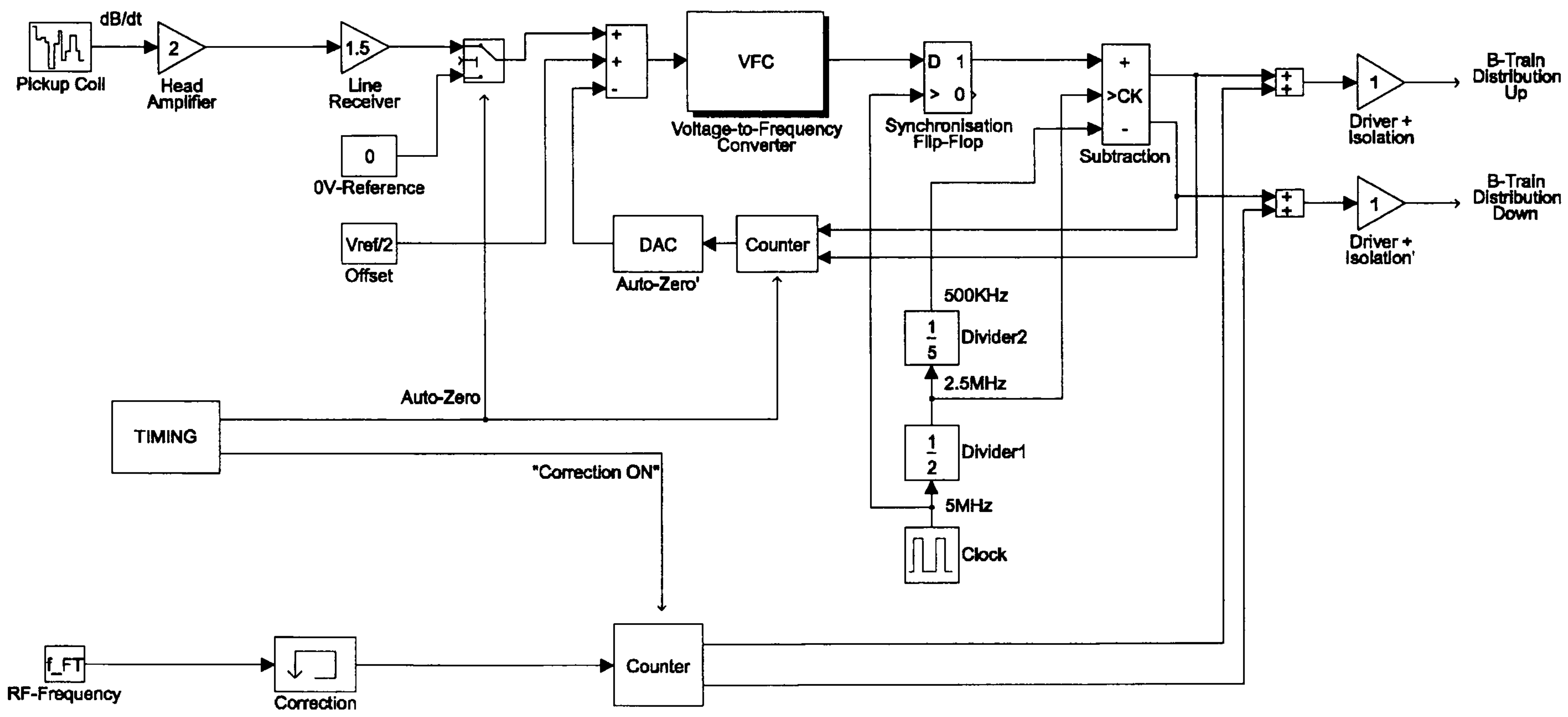
# PS Booster magnet control feed-back loops(2)

- Current Control Loop with underlying Voltage Loop
- Voltage Feed forward to minimise Control Loop Delay
- Digital DC-Filter Image to minimise the Dynamic Effects of the DC-Filter (overshoot)
- Feed forward of the Correction Power Supply Functions (Disturbance Feed forward) to reduce the Coupling (Disturbance) to the Main Power Supply
- Achievable Dynamic Precision over the whole Magnetic Cycle: ±100ppm (±0.4A / 4000A FS)
- Static (Flat Top) Precision: ~30ppm; limited by the content of 50Hz-harmonics on the magnet voltage

# PS Booster magnet, control aspects

- dB/dt Programming of the Magnetic Cycles from an Application Program running on a Workstation
- With the Knowledge of Magnet Inductivity and Resistance (both linear for the Booster) the Voltage and Current Reference Functions can be calculated

# Existing LEAR B-train




Block-Diagram of B-Train Generator of Antiproton Ring (LEAR)

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# Existing LEAR B-train (2)

- Principle:
  - **Voltage-to-Frequency Converter, Auto-Zero Function**
- Up-/Down-Train
- Resolution: 0.1 Gauss (~10 ppm of FS)
- Stability/Reproducibility: 1 Gauss (~100 ppm)
- Nonlinearity: 150 ppm
- Analog Zero Offset Correction (Auto-Zero)
- Stability limited by the missing gain correction (Auto-Calibration) and temperature stabilisation